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Walking through doorways causes forgetting: recall

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ABSTRACT

The aim of the current study was to explore how the location updating effect is affected when people are tested using recall rather than recognition, which is what has been done in prior work. Differences in the memory processes involved with these two tasks lead to predictions for two different patterns of data. In Experiment 1, memory was tested by having participants recall the single object they were carrying or had just put down, whereas in Experiment 2, people sometimes needed to recall both objects. It was found that, unlike recognition test performance, a similar location updating effect was found for both Associated (what was currently being carried) and Dissociated (what was recently set down) objects. Moreover, when both objects were correctly recalled, there was a bias to remember them in the order that they were encountered. Finally, if only one object was correctly recalled, it was the Associated object that was currently being carried. Overall, these results are consistent with the Event Horizon Model of event cognition.

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In a series of studies, we have shown that walking through doorways causes forgetting (e.g., Radvansky & Copeland, 2006). Specifically, people remember less about objects that they recently interacted with, particularly if they are currently carrying them, if they walk through a doorway compared to if they simply walk across a large room. This is called the *location updating effect*. This finding reflects a principle that the segmentation of experience into events can have a profound influence on cognition (Radvansky, 2012; Radvansky & Zacks, 2011, 2014). The aim of the current study is to explore how this pattern of remembering and forgetting is affected by using recall rather than recognition, as has been typically done. This is important because it is possible that the location updating effect is differentially impacted by recall and because people are more likely to engage recall following a move from one place to another rather than recognition.

In the basic location updating effect paradigm, using virtual environments, people pick up objects in one location, and then either walk across a large room (No-shift condition) or move to another room (Shift condition). When people are either halfway across the large room or have just entered the new room, a recognition probe is given (an object name). Typically, a recognition test is used in which the task is for people to respond "yes" if the probe item was either the object that they are currently carrying (the Associated object) or the one that they had just set down (the Dissociated object). People are to respond "no" to all other object names. The location updating effect is the finding that error rates are larger for the Shift condition than the No-shift condition. Moreover, this difference is typically only present, or at least larger, for the Associated objects. When the interaction between Shift/No-shift and Associated/Dissociated conditions has been tested, it has been significant, and simple effects tests have shown that the effect of Shift is significant for Associated, but not Dissociated, objects (Radvansky, Pettijohn, & Kim, 2015); Radvansky & Copeland, 2006. This outcome even extends to those who passively experience the shift (Pettijohn & Radvansky, Submitted). An examination of the data error rate data provided in Table 4 of Radvansky, Krawietz, and Tamplin (2011) suggests that this is generally, but not always, the case.

The location updating effect has been explained in the context of the Event Horizon Model of event cognition (Radvansky, 2012; Radvansky & Zacks, 2013, 2014, 2017). Essentially, when people move from one location to another, this spatial shift serves as an event boundary. At the event boundary, the event model for the prior location is removed from active working memory, and a new event model of the new location is created. Because the Associated objects are represented in two event models, namely one each for the prior and the current locations, a recognition probe activates both of these event models. These two event models then compete during retrieval, producing retrieval interference, and increasing error rates. This occurs even though they both point

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towards the same answer and working memory load is light, namely just two objects.

Explorations of the location updating effect have revealed a number of important features. It is observed when the probes are either pictures or verbal labels, when the to-be-remembered items were objects in the environment, or less integrated word pairs (Radvansky, Tamplin, & Krawietz, 2010). It also occurs when the immersion in the environment is reduced by using smaller displays, or is increased by using the real world in which people actually carried physical objects from one room to another (Radvansky et al., 2011). It is unaffected by normal ageing (Radvansky, Pettijohn, & Kim, 2015). The location updating effect is present regardless of whether the perceptual characteristics of the environment are similar or different, and even when people can preview the next location via transparent walls (Pettijohn & Radvansky, 2016a), and it is unaffected by the distance travelled or the introduction of a delay after traversing an event boundary (Pettijohn & Radvansky, 2016b). It is not merely a context-based effect, as returning to the room in which the object was originally encountered still results in worse memory performance (Radvansky et al., 2011). Interestingly, it even occurs when the shift from one location to another is not experienced, but only imagined (Lawrence & Peterson, 2016).

The aim of the current study was to assess how the location updating effect is affected when memory is tested using recall rather than recognition. As noted above, the explanation of the location updating effect when recognition for Associated objects is probed primarily reflects retrieval interference that is experienced when a probe item occurs in multiple events. In comparison, because the Dissociated object is no longer being carried by a person, it moves out of the foreground, thereby reducing its availability. Moreover, because the Dissociated object is not part of the current event model following a location shift, this new location's event model is not involved in producing retrieval interference because it is only associated with one set of retrieval cues.

For a recall test, as with recognition, it is expected that information about the Associated objects should be more available to people than the Dissociated objects. This is because they are foregrounded in the current event model by virtue of being actively carried by the participant. For example, when reading a narrative, people showed worse memory for an object when the protagonist was spatially separated from it while the protagonist remained in the foreground (Glenberg, Meyer, & Lindem, 1987). In the current study, rather than being presented with a recognition memory probe, people were asked to report either just the Associated object, the Dissociated object, or both. So, instead of seeing the name of an object as a probe, people needed to use their memory of the locations as cues to access the needed information. Below, we outline our predictions for the Associated and Dissociated objects in more detail.

For the Associated objects, in the No-Shift condition, a person can use the current location as a cue to recall what object was picked up. However, for the Shift condition, both the current and the prior location serve as recall cues, and retrieval interference should be experienced, just as it is for recognition. These two conditions produce interference. That said, there would be some reason to expect that memory for the prior location fades as a person is focused on the event model for the current location. It is difficult, if not impossible, to assess such fading on performance because there is no way to cleanly separate the influence of memory for the prior location from memory for the current location on Associated object performance.

In comparison, for the Dissociated objects, in the No-Shift condition, performance is expected to be worse compared to the Associated objects because the object is no longer part of the foreground of the current event model. However, in the Shift condition, there will be some fading of the prior event model, making the retrieval cues associated with the previous location harder to access, and so that location will be a less effective recall cue. As such, a location updating effect would be expected for both the Associated and Dissociated object conditions.

For the two object recall condition, the same foregrounding and fading of prior event models should affect recall previously discussed. In addition, because the Associated object is in the foreground of the current event model, it is likely that it will be the first item recalled and will appear more often when only one of the two items is recalled.

Experiment 1

To assess the consequences of using recall in a location updating effect paradigm, Experiment 1 used a single item cued recall task. Specifically, at each probe location, people were asked to recall the name of either the Associated or Dissociated object. If the same processes are operating in recognition and recall, then the interaction of Shift and Association would be significant, with the location updating effect being present for the Associated objects, and absent or smaller for the Dissociated objects. In contrast, if different factors come into play during recall, then it is expected that the interaction would not be significant, although the main effects of Shift and Association would be.

Method

Participants

Forty-eight people (19 female) were recruited from the participant pool in the Department of Psychology at the University of Notre Dame, and were given partial course credit. Five people were dropped for not following directions; four did not recall any dissociated items, and one did not recall any object colours. Data for two participants were lost due to experimenter error, leaving forty-one in the final sample.

Materials, apparatus, and procedure

As in previous studies, the virtual environments were created using the Valve Hammer editor (Valve Software, 2003). For Experiment 1, the displays were 46″ diagonal touchscreen monitors (Samsung model #460TSN-2). The virtual environment was a 55-room series of locations. The rooms were two possible sizes. The large rooms were twice the length of the small rooms. This room size difference allowed for the distance travelled in the virtual world to be equated in the Shift and No-shift conditions. Within each room were either one or two rectangular tables, with each table placed along a wall. There was only a single table for the small rooms, and a table in each half of the large rooms. On one table end was the to-be-picked-up object, whereas the other half was empty. This empty spot was for the object taken from the prior table to be set down. There were two doorways in each room, and they were never on the same wall. The objects that people interacted with were combinations of shapes and colours. The shapes were: cube, wedge, pole, disc, cross (X), and cone, and the colours were: red, orange, yellow, green, blue, purple, white, grey, brown, and black. All combinations of shapes and colours were used once within the experiment. Although all shape-colour combinations were seen, not all were probed.

After signing an informed consent form, people sat approximately .5 metres from the display. Thus, the virtual world largely filled their field of view. To make the experience seem more immersive, they wore headphones in which they could hear their own "footsteps" as they moved through the environment, and the lights were turned off in the room during the experiment.

People were told that the task was to pick up an object from a table, move to the next one by either moving across a large room (No-shift) or by moving through a doorway to the next room (Shift), place the object on the next table, pick up the next object, and so on. Picking the objects up and setting them down was done by using the touchscreen. People used their nondominant hand to touch either the empty part of the table to set an object down or the object already on the table to pick it up.

People moved through the virtual environment using a joystick held in their dominant hand. To ensure that people moved through the rooms in the appropriate order, after a room was entered, the door behind them closed. The door to the next room did not open until the object being carried was set down on the table and the new object was picked up. In large rooms, an invisible wall prevented a person from crossing the room before setting the object down and picking the next object up.

To assess objects' availability to memory, there were 48 probe trials. To make the timing and occurrence of probes less predictable, people were not probed following every shift or in the middle of every room. On probe trials, immediately upon either moving halfway across a long room or moving into a new room, a probe appeared in the middle of the screen. At this time, the screen dimmed and movement was disabled, but the virtual environment could still be seen. People were told to recall either the object they were currently carrying, or the one that they had just set down. Participants typed their responses into a textbox that appear below the probe question. After entering their response, the task continued. The experimental procedure typically lasted between 15 and 20 minutes.

Results and discussion

The recall accuracy data are reported in Table 1. Each data type was submitted to a 2 (Shift: same or different location) × 2 (Object: Associated or Dissociated) repeated-measures ANOVA. For the recall accuracy data, the main effect of Shift, $F(1,40) = 7.42$, $MSE = 0.015$, $p = .010$, $\eta_p^2 = .16$, was significant, with people performing worse after a spatial shift, consistent with the pattern observed using recognition. Moreover, there was a significant main effect of Object, $F(1,40) = 6.42$, $MSE = 0.022$, $p = .015$, $\eta_p^2 = .14$, with people being more accurate for the Associated objects that were currently being carried than the Dissociated ones that were set down. The interaction was not significant, $F < 1$. This pattern of data shows that the location updating effect can be observed with recall testing. However, this pattern of data differs from what has been repeatedly observed with recognition testing in that a location updating effect is observed for both the Associated and Dissociated objects. In the typical recognition test, the main finding is that performance is best in the No Shift-Associated condition and similar in the remaining three conditions. As can be seen in Table 1, there is more differentiation in the results when recall is used. As expected, performance is best in the No Shift-Associated condition; however, it is nominally worse in the Shift-Dissociated condition.

Overall, the results of Experiment 1 support the idea that the nature of location updating effect can be altered to some degree, when recall rather than recognition is used. Specifically, the demands of a recall task place a greater emphasis on both what is in the current foreground of an event model, as well as the effectiveness of the spatial locations as retrieval cues. When foregrounding

Table 1. Recall rates (in proportions) for Experiment 1. Standard errors are in parentheses.

	Recall accuracy	
	No-shift	Shift
Associated	.902 (.02)	.838 (.02)
Dissociated	.831 (.02)	.792 (.02)

and location cue are combined, performance is best. When one of these is missing (i.e., foregrounding but no location cue or no foregrounding but location cue), performance suffers, and when both are missing, performance is worse.

Experiment 2

The aim of Experiment 2 was to assess how the location updating effect may be affected if both the Associated and Dissociated objects were to be recalled rather than just one or the other. According to our account, people can use the locations as recall cues to help them report the names of the objects. For the No-shift condition, the same location can be used as a cue for both the Dissociated and the Associated object. However, for the Shift condition, because two locations are needed, it should be more difficult than the No-shift condition. Moreover, it is expected that people will be more likely to recall the Associated object first, because it is the foreground of the event model. Finally, if only one object is correctly recalled, it will be the Associated object.

Method

Participants

Ninety-seven people (64 female) were recruited from the participant pool in the Department of Psychology at the University of Notre Dame, and were given partial course credit. Nine people did not complete the experiment due to motion sickness, leaving 88 in the final sample.

Materials, apparatus, and procedure

The same equipment, virtual environments, and target objects were used as in Experiment 1. The primary difference was the inclusion of One Object and Two Object recall trials. For One object trials, people were asked to recall the Associated object, whereas for Two Object trials, people were asked to recall both the Associated and the Dissociated object. Within each of these conditions, some of the trials involved a spatial shift and some did not. Because of an error in the programme, the number of trials for each condition varied across the subjects. For 73 participants, for the One Object condition, there were 7 trials in No-shift condition, and 16 in the Shift condition, and for the Two Object condition, there were 7 trials in No-shift condition, and 19 in the Shift condition. However, for 15 participants, for the One Object condition, there were 6 trials in No-shift condition, and 18 in the Shift condition, and for the Two Object condition, there were 8 trials in No-shift condition, and 17 in the Shift condition. Because of this, the data are reported in terms of the accuracy rates for the proportion of trials a given participant received. The experimental procedure typically lasted between 15 and 20 minutes.

Results and discussion

The recall accuracy data are reported in Table 2. Each data type was submitted to a 2 (Shift: same or different location) × 2 (Objects: One or Two) repeated-measures ANOVA. For the recall accuracy data, the main effect of Shift, $F(1,87) = 38.95$, $MSE = 0.012$, $p < .001$, $\eta_p^2 = .31$, was significant, again with people performing worse after a spatial shift. There was also a main effect of Object, $F(1,87) = 72.67$, $MSE = 0.020$, $p < .001$, $\eta_p^2 = .46$, with people being more accurate when there was one object to be recalled rather than two. Finally, the interaction was not significant, $F(1,87) = 1.18$, $MSE = 0.007$, $p = .28$, $\eta_p^2 = .01$. Thus, the location updating effect was observed.

A further issue that can be pursued with these data is, when both of the objects were correctly recalled, which of the two was recalled first. On the one hand, it is possible that the associated item, which is part of the current event model, will be biased to be the first item recalled. On the other hand, because there is a bias to retrieve event information in a forward order (Anderson & Conway, 1993), it is possible that there would be a bias to recall the dissociated item first. To explore this, recall reports were analysed for trials when both Associated and Dissociated items were correctly recalled. This analysis revealed that there was a bias to report the Dissociated objects first ($M = .57$; $SE = .03$) more often than the Associated objects, $F(1,89) = 7.49$, $MSE = 0.107$, $p = .007$, $\eta_p^2 = .08$. Thus, overall the bias to retrieve event information in a forward order appeared to be having a stronger influence on performance. That said, it should also be noted that the magnitude of this effect is not very large.

Other analyses of temporal order for objects encountered before or after spatial shifts also support this forward-order bias. For example, in a similar experiment, objects were presented to participants who navigated virtual rooms. However, instead of interacting with the objects, people made a natural vs. man-made judgement of the object. After navigating the entire environment, people were given a forced-choice decision task about which object came before or after a target object. People performed better when the items were encountered in the same room (Horner, Bisby, Wang, Bogus, & Burgess, 2016). This suggests that there was a spatial updating effect in which memory for items separated by a spatial shift was worse. Additionally, the first experiment also showed a trend for higher accuracy in the "which came next?" condition which suggests a bias to remember the items in the order in which they were

Table 2. Recall rates (in proportions) for Experiment 2. Standard errors are in parentheses.

	Recall accuracy	
	No-shift	Shift
One Object	.967	.885
	(.01)	(.01)
Two Objects	.829	.767
	(.02)	(.02)

encountered. Another study found a similar temporal order bias when memoranda were photos separated by semantic category (DuBrow & Davachi, 2013). When photos of objects were paired with different colour boundaries, memory for the order was better for within-event (same-colour) photos compared to across-event photos. Further, order memory for items encoded in different events was worse than for items encoded in similar events, similar to an event updating effect (Heusser, Ezzyat, Shiff, & Davachi, 2018). A similar analysis with the data reported here is problematic because when the two-item recall was tested and the items were encountered in the same room, the recall probe always came after a spatial shift.

We also assessed recall performance in terms of which of the two objects was correctly recalled when only one was. Here, there is a fairly clear prediction that if only one object is correctly recalled, it would be the Associated object because it is part of the current event model. Consistent with this, we found that if only one of the object was correctly recalled, it was more likely to be the Associated object ($M = .11$; SE = .01) than the Dissociated object ($M = .07$; SE = .01), $F(1,89) = 11.74$, MSE = 0.005, $p = .001$, $\eta_p^2 = .12$. Thus, the object associated with the current event model was more likely to be reported if only one of the two were. This is consistent with the idea that the current event model has not been subject to processes that would result in forgetting and the loss of knowledge.

Overall, the results of Experiment 2 support the idea that the nature of the location updating effect is altered to some degree, when recall rather than recognition is used. In this case, both of the objects were to be recalled rather than just one. Like Experiment 1, a location updating effect was evident for both the Associated and Dissociated objects, and this effect was of similar magnitude in both cases. Moreover, the current experiment also revealed a small bias to report the two objects in the order in which they were encountered, consistent with a forward order bias that has been observed in other event memory research (Anderson & Conway, 1993). Finally, it was found that if only one of the two objects was correctly recalled, it was more likely to be the Associated object. This is consistent with the idea that this object is more likely to be in the foreground of the current event model.

General discussion

The aim of the current study was to assess whether the location updating effect is influenced by using recall rather than recognition memory testing. Our results revealed that, across two experiments, the location updating effect was observed. However, the pattern of data differed from what has been found with recognition testing. Specifically, for recognition testing, the location updating effect is typically isolated to the Associated objects that are currently being carried, but not for the Dissociated objects that were recently set down. In contrast, in the current study, the location updating effect was observed for both object types, and this effect was of similar magnitude in both cases. This is consistent with the idea that during recall, people may be using memory for the locations as retrieval cues to report the objects.

According to our theoretical view, recall is overall better for the Associated objects than the Dissociated objects because they are in the foreground of the current event models by virtue of the fact that people are still carrying them. This was supported by the significant main effect of Object observed in both of the experiments.

Moreover, for the Associated objects, it was predicted that people would recall more in the No-shift than the Shift condition as has been found with recognition testing. For the No-shift condition, that object is part of only a single event model, and so retrieval is relatively simple and straightforward. However, for the Shift condition, the Associated object is part of two event models, one for the current location, and one for the prior location. These two event models produce retrieval interference, thereby compromising performance.

In comparison, for the Dissociated objects, performance is better in the No-Shift condition because only the current location is needed as a retrieval cue. Because people are still in that location, it is easier to use it as a recall cue, and performance is better. However, in the Shift condition, the location cue needed for recall is the prior location. Memory for that location has begun to fade, and, as such, that location will be a less effective retrieval cue, rendering performance worse for the Shift trials.

One possible mechanism that can explain the difference between the patterns of results found when recognition, rather than recall, is tested is that the recognition probes serve as more direct cues to a memory trace. People access the relevant event models that contain those components. Associated objects are more likely to be in the foreground of the event model (Glenberg et al., 1987), so are more likely to result in better performance. Moreover, in the No-shift condition, there is only a single-event model, which is in the foreground. In the Shift condition, the event model for the new location and the prior location are causing inference because there are two models that contain the target object. An examination of the data presented in Table 4 of Radvansky et al. (2011) shows that there is generally a nominal shift effect observed for Dissociated objects when recognition is tested.

In comparison, for recall, people need to more actively search through memory using some sort of retrieval plan. This plan would access those event models that contain the needed information. As such, retrieval inference may play less of a role. What may be more necessary is the number of event models that need to be accessed rather than whether the information is foregrounded or not. In the No-shift condition, only one event model is involved, whereas in the Shift condition, two event models are involved. This is true for both the Associated and Dissociated objects. As such, the presence of a shift or not should have an influence in both of these cases.

In conclusion, this research demonstrates that even though there are some differences in the pattern of memory performance as a function of whether memory is assessed using recognition or recall, memory is clearly being influenced by the structure of the encountered events in both cases. Especially, when people walked from one room to another, there was a decline in the ability to remember. Walking through doorways causes forgetting. This pattern of remembering and forgetting is guided primarily by how people create and organise their event models as a function of the encountered environmental structure. Moreover, the ability to access that information is modified, but not negated, by the cognitive processes that are used to retrieve the desired knowledge.

Disclosure Statement

No potential conflict of interest was reported by the authors.

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References

Anderson, S. J., & Conway, M. A. (1993). Investigating the structure of autobiographical memories. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *19*(5), 1178–1196.

DuBrow, S., & Davachi, L. (2013). The influence of context boundaries on memory for the sequential order of events. *Journal of Experimental Psychology: General*, *142*(4), 1277–1286.

Glenberg, A., Meyer, M., & Lindem, K. (1987). Mental models contribute to foregrounding during text comprehension. *Journal of Memory and Language*, *26*(1), 69–83.

Heusser, A. C., Ezzyat, Y., Shiff, I., & Davachi, L. (2018). Perceptual boundaries cause mnemonic trade-offs between local boundary processing and across-trial associative binding. *Journal of Experimental Psychology: Learning, Memory, and Cognition*. Advance online publication. http://dx.doi.org/10.1037/xlm0000503

Horner, A. J., Bisby, J. A., Wang, A., Bogus, K., & Burgess, N. (2016). The role of spatial boundaries in shaping long-term event representations. *Cognition*, *154*, 151–164.

Lawrence, Z., & Peterson, D. (2016). Mentally walking through doorways causes forgetting: The location updating effect and imagination. *Memory (Hove, England)*, *24*(1), 12–20.

Pettijohn, K. A., & Radvansky, G. A. (2016a). Walking through doorways causes forgetting: Environmental effects. *Journal of Cognitive Psychology*, *28*(3), 329–340.

Pettijohn, K. A., & Radvansky, G. A. (2016b). Walking through doorways causes forgetting: Event structure or updating disruption? *Quarterly Journal of Experimental Psychology*, *69*(11), 2119–2129.

Pettijohn, K. A., & Radvansky, G. A. (2018). *Walking through doorways causes forgetting: Active and passive interaction*. Manuscript submitted for publication.

Radvansky, G. A. (2012). Across the event horizon. *Current Directions in Psychological Science*, *21*(4), 269–272.

Radvansky, G. A., & Copeland, D. E. (2006). Walking through doorways causes forgetting: Situation models and experienced space. *Memory & Cognition*, *34*(5), 1150–1156.

Radvansky, G. A., Krawietz, S. A., & Tamplin, A. K. (2011). Walking through doorways causes forgetting: Further explorations. *The Quarterly Journal of Experimental Psychology*, *64*(8), 1632–1645.

Radvansky, G. A., Pettijohn, K. A., & Kim, J. (2015). Walking through doorways causes forgetting: Younger and older adults. *Psychology and Aging*, *30*(2), 259–265.

Radvansky, G. A., Tamplin, A. K., & Krawietz, S. A. (2010). Walking through doorways causes forgetting: Environmental integration. *Psychonomic Bulletin & Review*, *17*(6), 900–904.

Radvansky, G. A., & Zacks, J. M. (2011). Event perception. *Wiley Interdisciplinary Reviews: Cognitive Science*, *2*(6), 608–620.

Radvansky, G. A., & Zacks, J. M. (2014). *Event cognition*. New York: Oxford University Press.

Radvansky, G. A., & Zacks, J. M. (2017). Event boundaries in memory and cognition. *Current Opinions in Behavioral Science*, *17C*, 133–140.